Resistance Grounded Systems

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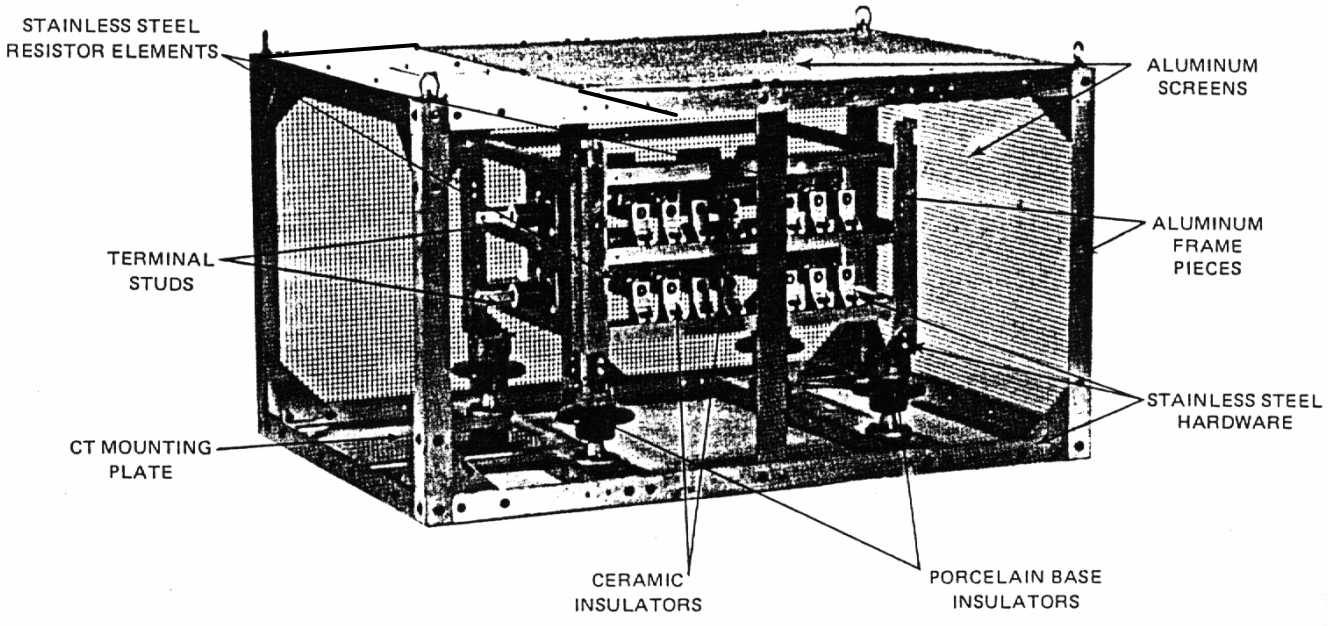
Purpose

In order to limit the fault current on transformers with a Wye connected secondary, neutral grounding resistors or reactors are often used in medium voltage systems. These current limiting devices are connected in series with the transformer secondary neutral. In the event of a phase-to-ground fault, the current will flow through, and be limited by, the neutral resistor or reactor.

Neutral Ground Resistor
Located adjacent to large substation transformer.



WESTINGHOUSE GROUNDING RESISTOR MOUNTED IN FREE STANDING SAFETY ENCLOSURE
(FRONT AND END SCREENS REMOVED)

Grounding

Resistance Grounded Systems
Resistor Specifications

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Ratings

The three electrical ratings required to select a grounding resistor are: Voltage Rating, Current Rating, and Time Rating. Resistor ratings are defined by IEEE Standard 32.

Voltage Rating

- The Grounding Resistor Voltage Rating is based on the system phase-to-neutral voltage. This voltage can be calculated by dividing the phase-to-phase voltage by $\sqrt{3}$. (Note: $\sqrt{3}$ = 1.732)

Current Rating

Resistance Grounding falls into two categories: Low Resistance and High Resistance

- In Low Resistance Grounded Systems the current is limited to 25 amps or more. Generally the range is from 25 to 600 amps, although in some systems it may be even greater.

- In High Resistance Grounded Systems the current is limited to 10 amps or less.

Time Ratings

Standard Time Ratings are: Ten Seconds, One Minute, Ten Minutes, and Extended Time (Required by MSHA).

The time rating indicates the time that the grounding resistor can operate under fault conditions without exceeding the specified temperature rise above a 30^{o} Ambient. Temperature rises are noted below:

Temperature rise for resistors with a rating of less than ten minutes - 760^{o} C
Temperature rise for resistors with a Ten Minute Rating and Extended Time Rating - 610^{o} C
Temperature rise for steady-state operation - 385^{o} C

Additional note on the extended time rating: In order to insure normal life of an Extended Time Rated Device, it shall not operate at its maximum temperature rise for more than an average of 90 days per year.

Application Considerations

- On systems with a voltage of 1000 volts or less (phase-to-phase) grounding resistors are not used. Normally these system use a solidly grounded configuration with no intentional impedance being introduced into the system.

- Resistance Grounding is recommended on Medium Voltage Systems from 1000 volts to 15,000 volts phase-to-phase.

- Because of the cost, Resistance Grounding is not usually used on systems above 15,000 volts phase-to-phase. Additionally, the use of a solidly grounded system allows for use of equipment which is insulated for the phase-to-neutral voltage of the system.

- When a system has protective relays which will trip the circuit if a ground fault occurs, a grounding resistor with a 10 Second Rating is often specified, because the relays will trip the system in less than 10 seconds. However, One Minute or Ten Minute ratings are sometimes used for an extra margin of safety, even though the cost will be greater.

- The Extended Time Resistor is normally used when it is necessary to let the ground fault persist for some time. An example being in the refining industry where it is very costly to shut down in mid-process. Therefore, the grounding system is designed to limit the ground fault current but does not shut down the system when the fault occurs. In a situation such as this, a method of indicating a ground fault will be used, such as lights or alarm annunciation, but the fault will not be cleared until an orderly shutdown can be planned. The Extended Time rating is also required by MSHA for coal mine applications, but here the rating is applied to achieve extra system reliability; these systems *are* required to trip as quickly as possible on any ground fault.

Resistance Grounded Systems
Typical MSHA System

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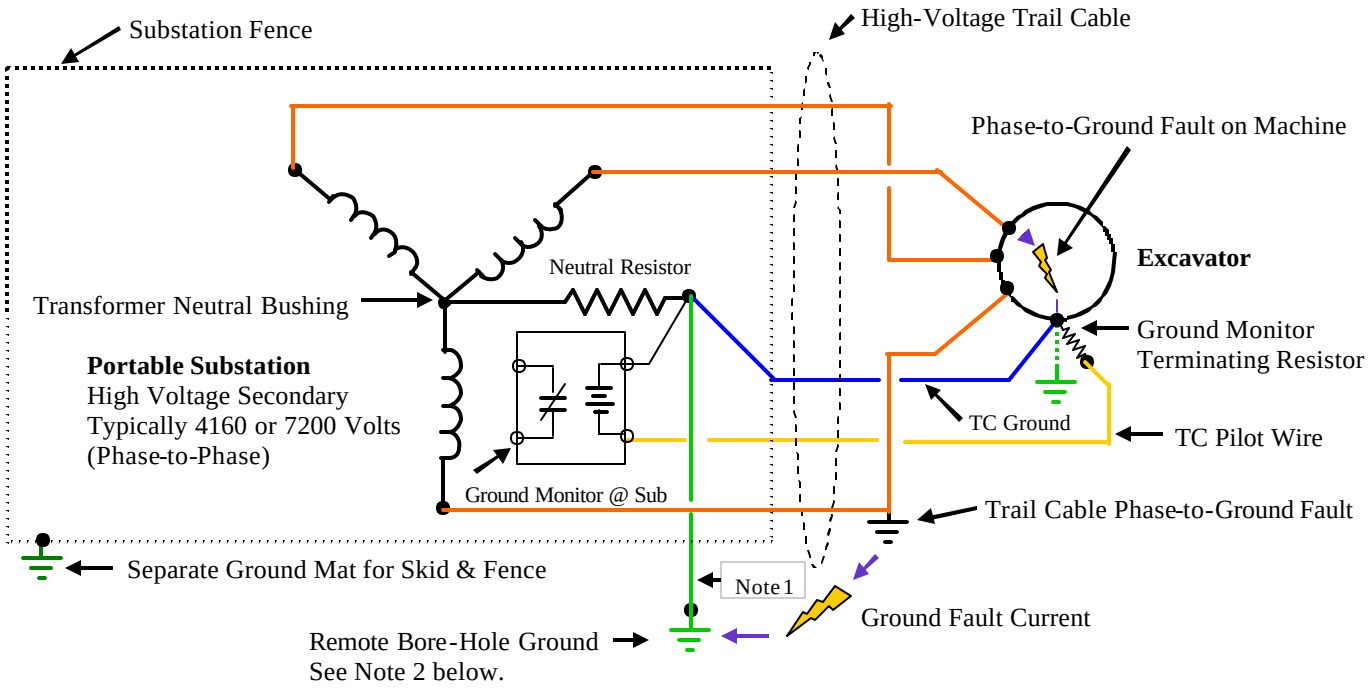
Resistance grounding is required by the Mine Safety and Heath Administration (MSHA) for transformers that supply low/medium and high voltage portable and mobile equipment in coal mines. See Sheets 5 and 6 for the Federal Register Part 77 regulations for Surface Coal Mines. The regulations for Underground Coal Mines are similar but are not included here; the underground regulations can be found in the Federal Register Part 75.

A typical resistance grounded neutral system for a high-voltage mining application is shown in the drawing below. Refer to Sheet 4 for a description of the ground monitor and protective relay operation.



Drawing Color Code: Red - Trail cable phase conductors (3), Blue - Trail cable ground conductor, Yellow - Trail cable pilot wire, Green - Ground, Violet - Ground fault current path .

- Note 1: The conductor connecting the Neutral Resistor to the Remote Ground must be insulated for the phase-to-phase voltage of the system.
- Note 2: According to the MSHA Inspection Guidelines, the resistance for the trail cable ground conductor and the remote ground-to-earth resistance are required to be 4 ohms or less. The Remote Ground must be located at least twenty-five feet (25') from the substation frame.

Fault Analysis

- In the example above, a phase-to-ground fault on the trail cable will cause fault current to flow back through the earth, from the earth into the remote ground, then back through the grounding resistor to the transformer neutral. (Depending on the nature of the fault, there may be some fault current which also flows back through the trail cable concentric ground if the ground conductor is still intact.)
- For a phase-to-ground fault on the machine, also illustrated above, fault current will return to the source through the trail cable ground conductor. (There may also be a parallel path through the earth as the heavy machine may be in good contact with the earth).

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Protective Relay Operation

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Ground Monitor Operation

Refer to drawing on Sheet 3.

The purpose of the Ground Monitor is to verify the integrity of the trail cable ground to the machine. Several different schemes are in use. One equipment manufacturer uses an ac frequency ground check signal, another circulates a direct current through the ground check loop.

In the illustration on the previous page, a low-voltage DC current is circulated from the monitor through the pilot wire to the machine and back to the monitor on the cable ground conductor. This is a fail-safe system; loss of the ground check current for any reason will be recognized by the monitor, drop out the ground check relay, and trip the main power circuit breaker.

This system will also recognize a shorted pilot wire-to-ground condition through the use of an electronic *window comparator* circuit which "looks" for the termination resistor mounted on the machine between the ground check conductor and the cable ground. The detector circuit is set for the series loop resistance which includes the cable ground conductor resistance, the ground check conductor resistance, and the terminating resistor resistance. A deviation from this set resistance value, either high or low, causes the main circuit breaker to trip The unit must be recalibrated when trail cable is added or removed.

Neutral Current and Potential Relaying

Refer to drawing below

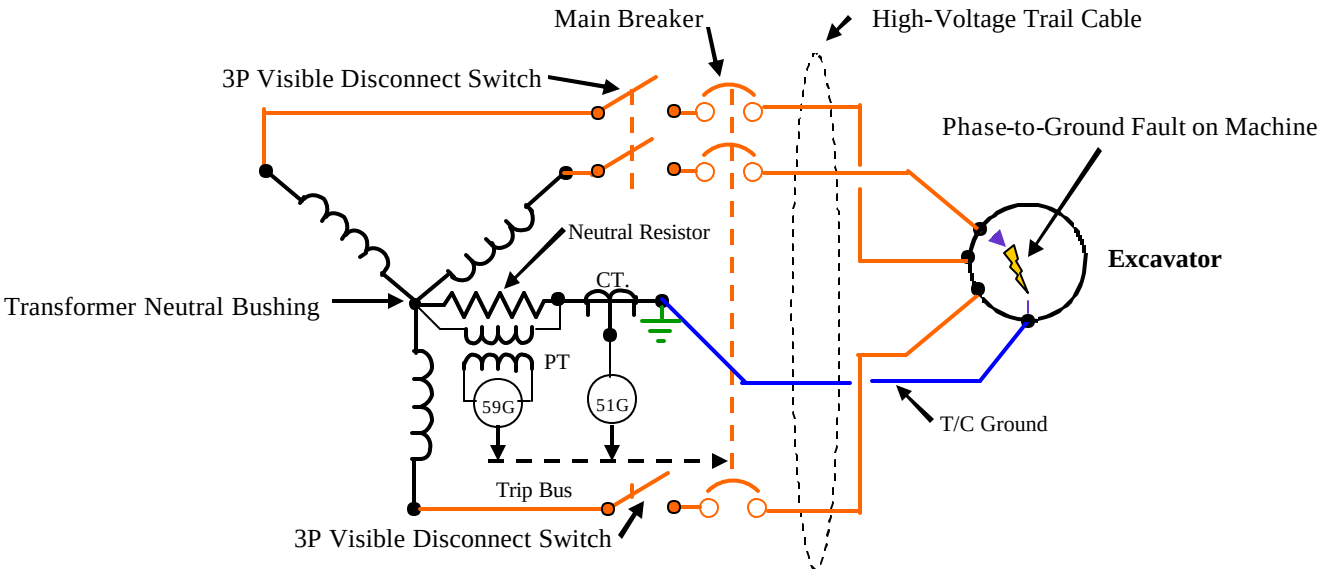
(For clarity, ground monitor and cable ground check conductor are not shown.)

Neutral Current Relaying

A ground fault will cause neutral current to flow which will be detected by the neutral Current Transformer (CT). If this current exceeds the pickup value of the Time Overcurrent Relay (51G), the main breaker will be tripped. Note: The neutral will also carry any unbalanced load current, so this relay needs to be set high enough that it will not trip due to unbalanced load. MSHA requires that all single-phase loads be connected phase-to-phase; see regulations on next page.

Potential Relaying

Ground faults can also be detected by the occurrence of a voltage which will appear across the neutral resistor when ground fault current flows through the resistor. A potential transformer (PT) is used which has a primary voltage the matches the phase-to-ground potential of the system; the PT 120 volt secondary is connected to the 59G Relay. This method has the advantage that it will function even if the ground resistor is open. For this reason Potential Relaying is often used to provide backup grounded-phase protection for resistance-grounded system.



Resistance Grounded Systems
Applicable MSHA Regulations

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Code of Federal Regulations (30 CFR) Part 77 for Surface Coal Mines

Subpart I - Surface High-Voltage Distribution

77.801 Grounding Resistors

The grounding resistor, where required, shall be of the proper ohmic value to limit the voltage drop in the grounding circuit external to the resistor to not more than 100 volts under fault conditions. The grounding resistor shall be rated for maximum fault current continuously and insulated from ground for a voltage equal to the phase-to-phase voltage of the system.

77.801-1 Grounding resistors; continuous current rating.

The ground fault current rating of the grounding resistors shall meet the "extended time rating" set forth in American Institute of Electrical Engineers, Standard No.32.

77.802 Protection of high-voltage circuits; neutral grounding resistors; disconnecting devices.

High-voltage circuits supplying portable or mobile equipment shall contain either a direct or derived neutral which shall be grounded through a suitable resistor at the source transformers, and a grounding circuit, originating at the grounded side of the grounding resistor, shall extend along with the power conductors and serve as a grounding conductor for the frames of all high-voltage equipment supplied power from that circuit, except that the Secretary or his authorized representative may permit other high-voltage circuits to feed stationary electrical equipment, if he finds that such exception will not pose a hazard to the miners. Disconnection devices shall be installed and so equipped or designed in such a manner that it can be determined by visual observation that the power is disconnected.

88.803 Fail safe ground check circuits on high-voltage resistance grounded systems.

On and after September 30, 1971, all high-voltage, resistance grounded systems shall include a fail safe ground check circuit or other no less effective device approved by the Secretary to monitor continuously the grounding circuit to assure continuity. The fail safe ground check circuit shall cause the circuit breaker to open when either the ground or ground check wire is broken.

77.803-1 Fail safe ground check circuits; maximum voltage.

The maximum voltage used for ground checks circuits under 77.803 shall not exceed 96 volts.

77.806 Connection of single-phase loads.

Single-phase loads, such as transformer primaries, shall be connected phase-to-phase in resistance grounded systems.

Resistance Grounded Systems
Applicable MSHA Regulations

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Code of Federal Regulations (30 CFR) Part 77 for Surface Coal Mines

Subpart J - Surface Low- and Medium-Voltage Alternating Current Circuits

77.901 Protection of low- and medium-voltage three-phase circuits.

(a) Low- and medium-voltage circuits supplying power to portable or mobile three-phase alternating equipment shall contain:
(1) Either a direct or derived neutral grounded through a suitable resistor at the power source;
(2) A grounding circuit originating at the grounded side of the grounding resistor which extends along with the power conductors and serves as a grounding conductor for the frames of all the electric equipment supplied power from the circuit.
(b) Grounding resistors, where required, shall be of an ohmic value which limits the ground fault current to no more than 25 amperes. Such grounding resistors shall be rated for maximum fault current continuously and provide insulation from ground for a voltage equal to the phase-to-phase voltage of the system.
(c) Low- and medium-voltage circuits supplying power to three-phase alternating current stationary electric equipment shall comply with the National Electric Code.

77.901-1 Grounding resistors; continuous current rating.

The ground fault current rating of the grounding resistors shall meet the “extended time rating” set forth in American Institute of Electrical Engineers, Standard No.32.

77.902 Low- and medium-voltage ground check monitor circuits.

On and after September 30, 1971, three-phase low- and medium-voltage resistance grounded systems to portable and mobile equipment shall include a fail safe ground check circuit or other no less effective device approved by the Secretary to monitor continuously the grounding circuit to assure continuity. The fail safe ground check circuit shall cause the circuit breaker to open when either the ground or pilot check wire is broken. Cable couplers shall be constructed to cause the ground check continuity conductor to break first and the ground conductor last when being uncoupled when pilot check circuits are used.

77.902-1 Fail safe ground check circuits; maximum voltage.

The maximum voltage used for ground check circuits under 77.902 shall not exceed 40 volts.

77.905 Connection of single-phase loads.

Single-phase loads shall be connected phase-to-phase in resistance grounded systems.